Applied Innovative Research
Vol. 2, March 2020, pp. 120-128

Pollution Control: A brief review of conventional and nano technological approaches

Vandita Srivastava
Department of Physics, Kanahiya Lal D A V (P G) College, Roorkee 247 667, India

Recieved 31 January 2020

Environmental pollution is one of the major crisis throughout the whole world today, causing major health problems. The contaminants are found in all the three phases of the environment. The air pollutants include CO, CFCs, VOCs, nitrogen oxides etc. Water and soil are contaminated due to sewage and industrial wastes, pesticides, fertilizers etc. Recent advancement in the field of nanotechnology has provided new nanomaterials and methods for combatting pollution which are more effective than conventional methods. Nano technology can be used in three ways, namely, remediation and treatment, pollution prevention and detection and sensing. Remediation methods include adsorption, semiconducting material photocatalytic remediation and filtration using different types of nano materials. Nano technology provides an environment friendly solution with less waste and reduction of toxic wastes into non-toxic products. Sensing and detection of the pollutants is an important step in controlling pollution. Conventional methods need expertise, more time and are costly and these cannot give the concentrations of the pollutants instantly. On the other hand, nanosensors can detect the pollutant at ppm and ppb levels accurately due to small size and high surface/volume ratio. The enormous growth of nanotechnology during the last decade in search of new materials with enhanced and/or typical properties with wide range of applications has also produced hazardous nanowastes too. The need of the hour is to properly assess the health hazards due to engineered nanoparticles including their fabrication, storage and distribution, application and disposal.

Keywords: Nano technology, Pollution control, environmental remediation, Detection and sensing, Nano filters

1 Introduction

Environmental pollution is one of the major global crisis, caused by toxic chemicals in air, water and soil, thus affecting all the three phases of the environment[1].The contaminants include particulate matter, combustion byproducts (CO, NO_2, SO_2 etc.), volatile organic compounds (VOCs), particles and aerosols from dust and smoke; toxic trace metal elements like chromium, arsenic, lead; pesticides, fertilizers, herbicides, oil spills, industrial wastes containing toxic chemicals and sewage[2-4]. Increased pollution levels result not only in the destruction of biodiversity, but also in the degradation of human health causing respiratory problems, lung and heart diseases, high blood pressure, cancers, neurological disorders, kidney and skin diseases[5,6] and need an urgent and effective solution from recent technological discoveries.

Recent advancement in the field of nanotechnology has provided novel nano materials and methods for combatting pollution which are more effective than conventional methods[7]. Nanotechnology offers many advantages to improve existing environmental condition with three main capabilities including cleanup, sensing and detection and prevention. Nano materials possess enhanced reactivity due to their higher surface to volume ratio are more effective than their bulkier counterparts. Composite nano materials are also being developed which are more effective than single nanoparticle materials. In this paper, first the sources of various environmental pollutants in air, water and soil, along with the conventional methods of their removal are described mentioning their drawbacks as well. The next section gives the brief introduction of nano materials and their properties followed by their applications in environmental remedies and protection. It also discusses the role of molecular nano technology in environmental remediation.

2 Environmental Pollution and Conventional Methods for Its Removal

Contamination of all the three phases i.e. air, soil and water of the environment with biological, physical and/or chemical pollutants is referred to as environmental pollution. Air pollutants include

*E-mail: vandita61@gmail.com

particulate matter like dust, suspended particulate matter (**SPM**) and respirable suspended particulate matter (**RSPM)** in air are the major causes of mortality and morbidity. Gaseous pollutants include oxides of sulfur & nitrogen CO, CO_2 emitted from the vehicles or burning of fossil fuel along with O_3, etc[8-10]. Biological pollutants such as bacteria, virus and pollen etc. cause viral infections like influenza, measles. Molds and mildews release disease-causing toxins. Sneezing, watery eyes, coughing, shortness of breath, dizziness and digestive problems are common symptoms developed by biological pollutants[11, 12]. These can trigger allergic reactions, including hypersensitivity pneumonitis, allergic rhinitis, and asthma[13].

Domestic wastes, insecticides and herbicides, pollutants from livestock operations, phosphates, nitrates, volatile organic compounds (VOCs), heavy metals, chemical waste/ industrial wastes e.g. cyanides (toxic), sewage etc. are major water pollutants[14] whereas pesticides, herbicides, ammonia, petroleum hydrocarbons, lead, nitrates and toxic metals like mercury, cadmium, manganese, arsenic in excess amount that degrade the soil quality are the major soil pollutants[7] . Industrialization and human activities produce hazardous/toxic wastes contaminating the environment which adversely affects all the living beings. It leads to global warming due to release of GHGs in the atmosphere In addition, air pollution creates an imbalance in the earth's atmosphere and causes the depletion of the Ozone layer, essential for the life on the earth. Agricultural activities also contaminate our environment with the extensive use of insecticides, pesticides and fertilizers for boosting the crop production. The harmful chemical, thus, enters in the food chain of humans/animals in turns affects human health[15]. The pollution has reached to such a level, that it has become a global menace[8].

2.1 Physical processes for the removal particulate matter

Physical processes use cyclones, scrubbers, electrostatic precipitators, and bag house filters[16]. In a cyclone particulates are removed from the dirty air when it is allowed to enter into a cyclone tangentially causing it to flow in a spiral path inside a cylindrical chamber. The larger particulates are thrown outward to strike the chamber wall and slowed by friction, then slide down and collected at the bottom of the cyclone. The cleaned air swirls upward in a narrower spiral through an inner cylinder and emerges from an outlet at the top. This method is good for removing relatively coarse particles greater than 20micron with 90% efficiency. They are typically used as pre-cleaners and are followed by more efficient air-cleaning equipment.

Wet scrubbers are another air cleaning device. In a spray-tower scrubber, an upward-flowing airstream is washed by water sprayed downward from a series of nozzles. The water is recirculated after it is sufficiently cleaned to prevent clogging of the nozzles. It can remove 90% of particulates larger than about 8μm.Venturi scrubbers are the most efficient with efficiencies of more than 98% for particles larger than 0.5μm in diameter. Wet scrubbers are usually applied to control of flammable or explosive dusts.

In an electrostatic precipitator, particles suspended in the airstream are given an electric charge as they enter the unit and are then removed by the influence of an electric field. One of the most efficient devices for removing suspended particulates is an assembly of fabric-filter bags, commonly called a baghouse. It comprises an array of long, narrow bags suspended upside down in a large enclosure. Dust-laden air is blown upward through the bottom of the enclosure by fans. Particulates are trapped inside the filter bags, while the clean air passes through the fabric and exits at the top of the baghouse.

2.2 Removal of gaseous pollutants

Gaseous pollutants including volatile organic compounds (VOCs) and other toxic as well as greenhouse gases are controlled by means of absorption, adsorption, condensation and incineration either singly or in combination. By combustion, the organic pollutants in the form of gases or vapors are converted into water vapor and relatively less harmful products, such as CO_2[17]. In Absorption, the gaseous effluents are passed through scrubbers or absorbers containing suitable liquid absorbent, that removes/modifies one or more of the pollutants present in it whereas in adsorption, the gaseous effluents are passed through porous solid absorbents kept in a container. This creates a film of the adsorbate on the surface of the adsorbent as the organic/inorganic constituents of the effluent gases are trapped at the interface of the absorbent. Carbon sequestration process is used for controlling carbon dioxide levels. It is a biophysical process by which the atmospheric carbon dioxide is transformed into biomass and thus decreasing the amount of greenhouse gases in earth's atmosphere[18].

2.3 Removal of pollutants from water/ waste water

Traditional method used in municipal waste water treatment plant (WWTP) has in general two stages of treatment: mechanical and biological; the third stage of treatment with advanced technologies is very rare due to their high operational cost. During mechanical stage suspended matter is removed by filtration, coagulation, filtration with coagulation, precipitation, ozonation, adsorption sedimentation, and flotation processes. In biological treatment the removal of organic pollutants takes place via biodegradation (biotransformation) and sorption on activated sludge Removal of organic pollutants from municipal wastewater can also take place by means of volatilization for volatile pollutants. Adsorption is found to be an excellent phenomenon in which common mechanism is applied for organic and inorganic pollutants removal from the wastewaters[19, 20]. The ability of agro-waste material coconut shell to remove Cr (VI) from wastewater is also investigated[21]. These conventional water treatment processes are not able to remove a wide spectrum of toxic chemicals and pathogenic microorganisms in raw water.

2.4 Soil pollution remediation

Addition of excessive chemicals due to fertilizers, pesticides, insecticides, drainage from various industries, heavy metals and radioactive wastes, garbage, hospital wastes, construction material wastes, detergent in the sewage water, oil due to exploration and refining and then its transportation, acid rain covers a wide range of causes for soil pollution. These can change the physical, chemical and biological properties of the soil. This disturbs the biological activities of the soil. It is considered that soil pollution is controlled automatically by nature. However, the pollution has reached to such a level that nature is unable to cope with it and thus self-sustainability is impossible. So, external agents/ methods are to be applied to remove these soil pollutants. Soil pollution can be greatly controlled by proper waste disposal/management i.e. by creating/ identifying areas for dumping domestic wastes, incineration and recycling, incineration being the worst producing poisonous gases. Also the metal ion removal through chemical precipitation, reverse osmosis and solvent extraction neither provide a complete removal of pollutants nor are energy efficient and also generate toxic wastes, the disposal of which is another problem. For these, phytoremediation is found to be an environment friendly, low cost, solar energy driven natural clean up technique in which plants are used to remove the contaminants[22]. In this method, plants are grown in a contaminated matrix, for a required growth period to remove contaminants from the matrix or facilitate immobilization or degradation (detoxification) of the pollutants. Phytoremediation can be done in three way namely phytoextraction, rhizofiltration, and phytostabilization. In phytoextraction the metal contaminants in the soil are taken up by plant roots into its portions above ground[23]. One or a combination of these plants is selected and planted at a particular site based on the type of metals present and other site conditions. After the growth period of the plants, they are harvested and either incinerated or composted to recycle the metal rhizofiltration is similar to phytoextraction, except that the plants to be used for cleanup, are first raised in greenhouses with their roots in water rather than in soil. After the root system has been developed, they are planted in the contaminated area where the roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested. Certain plant species immobilize contaminants in the soil and ground water through absorption and accumulation by roots and prevent their migration to the ground water reducing the bio-availability of metal in the food chain. This process is called phytostabilization. Different metals are different mobility within a plant, e.g., Cd and Zn are more mobile than Cu and Pb. During the transportation through the plant, metals are bound largely on the cell walls of roots, leading to high metal concentration in plant roots. Some microbes can also reduce plant metal uptake or translocation to aerial plant parts by decreasing metal bioavailability in soil via precipitation, alkalinization, and complexation processes.

2.5Merits and demerits of conventional methods of pollutants removal

Table 1 summarizes various pollutants removal techniques along with their advantages and disadvantages. It shows that the processes which are easy and affordable, are less effective with low efficiency, whereas effective techniques are expensive. Also some may produce harmful byproducts. Biological degradation is environment friendly, inexpensive but very time consuming. The pollution, now a days, is increasing at such an alarming rate that we need solutions which are efficient, fast,

Table1 — Different pollutants removal techniques with their advantages and disadvantages.

Removal techniques	Advantage(s)	Disadvantage(s)
Electrochemical oxidation	Does not require auxiliary chemicals, high pressures, or high temperatures.	Low selectivity and low reaction rates.
Biological process	Ecologically favorable process.	Costly, handling & disposing secondary sludge pose problems.
Adsorption	Cost-effective, Easy operation, more efficient than precipitation, solvent extraction, filtration, etc.	Merely removes the pollutants from one phase (aqueous) to another
Advanced oxidation processes (AOP)		
(i) Ozonation	Powerful oxidation technique for a large number of organic & inorganic materials.	Complex technology, requires high operational cost. High electric consumption.
(ii) UV	Effective method with no byproducts harmful to the environment.	Less effective if the wastewater has high amounts of particulates which can absorb UV light.
(iii) UV/H_2O_2	An effective technique in the oxidation and mineralization of most organic pollutants.	Less effective, when the wastewater has high absorbance. High operational cost.
(iv) O_3/UV/H_2O_2	Most effective process due to the fast generation of $^{\cdot}OH$ radicals, can treat a wide variety of contaminants.	Needs to compete with high turbidity, solid particles, and heavy metal ions in the aqueous stream, High operational cost.
(v) Fenton reaction	Simple process. Easy availability of chemicals.	Production of sludge iron waste and handling the waste pose logistical problems.
(vi) Photo-Fenton reaction	Reduction of sludge iron waste compared to original Fenton reaction. Effective and fast degradation.	A controlled pH medium needed for enhanced performance.
(vii) Heterogeneous photocatalysis	Long-term stability at high temperature. Low-cost	Can produce byproducts that are harmful to the environment. Requires efficient catalysts that can absorb in the visible region.

environment friendly and cost effective too. Recent advancement in the field of Nano technology can provide better and effective options for environmental management and sustainable development.

3 Nanotechnology and Nanomaterials

The term nanotechnology was first proposed by Richard Feynman in 1959. It refers to processes for fabrication and usage of nano scale structures. Nano materials can be classified into following categories:

i. zero dimensional nano structures- structures having all the three dimensions at nanoscale (<100nm). ex. nano particles, nano powder, quantum dots.

ii. one dimensional nano structures - structures having two dimensions at nanoscale. ex. nano tubes, nano rods, nano fibers.

iii. two dimensional nano structures- structures with one dimensions at nanoscale ex. -nano thin films, nano coating, grapheme.

iv. three dimensional nano structures-Those materials which are bulky in nature with all dimensions above 100 nm, but contain 0D, 1D and/or 2D nanostructures ex-fullerene.

Figure 1 depicts the above mentioned different types of nano structures.

Nano materials have completely different properties as compared to their bulk counterparts. Nano materials possess enhanced reactivity due to their higher surface to volume ratio. This increases the reactivity and hence efficiency of nano materials. In addition, nanomaterials can be attached to the desired functional groups to target specific pollutants for efficient remediation. The physical properties such as size, morphology, porosity and chemical composition of the nanomaterials can be tuned to have desired performance of the material for contaminant remediation. The hybrids/composites developed using combination of several different materials are found to be more efficient, selective, and stable than by using a single type of nanomaterial. These observed changes at nano scale lead to the applications of nano materials in almost every field ranging from energy, textiles, electronics, construction, food and military to medicine, health and environment. They show high efficiency and performance with less energy consumption.

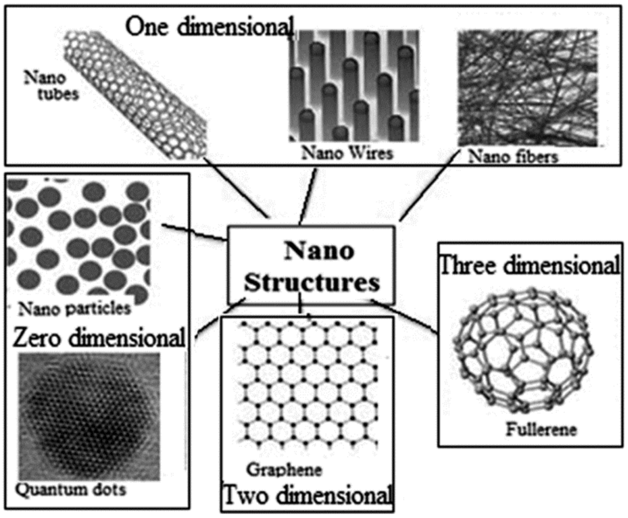

Fig. 1 — Different types of nanostructures.

3.1 Environmental nanotechnology

Environmental Nanotechnology refers to the application of nanotechnology in redressing the environmental pollution problem in all its three phases i.e. solid, liquid and gas. It can be done in three ways, namely, remediation and treatment, pollution prevention and detection and sensing. In the following sections, these are described separately.

3.1.1 Treatment and remediation

The processes used in the treatment and remediation of the environmental pollutants are adsorption by nano adsorptive materials, their degradation by nano catalysts into simpler compounds and separation or filtration by using nano filters.

3.1.2 Nano remediation of air pollution

Carbon nano structures e.g. grapheme, fullerene and carbon nanotubes etc. with extreme physical properties and highly reactive surface sites are proven to be excellent adsorbents for the removal of various air pollutants including greenhouse gases[25]. Silica nanoparticles have also been applied in removal of gaseous pollutants such as CO_2, aldehydes & ketones (with amine-modified alumino-silicate and porous silica) along with dyes and heavy metals (with carboxylic acid-, amino-and thiol functionalized silica), from waste waters due to high surface area, large pore volume, facile surface modification and tunable pore size[26]. The other method to control air pollution is by semiconducting material photocatalytic remediation. Nanocatalyst can improve the reaction efficiency. The photocatalytic properties of TiO_2 are utilized in designing a coating that can reduce the atmospheric contaminants like NO_x and VOCs. TiO_2 and nano materials of silver, titanium and zinc possess antimicrobial properties, so can be used for disinfecting water from bio pollutants. Silica nanoparticles can remove atmospheric lead. Nanostructured membranes are used for dust removal by air filtration. Nano technology reduces the waste production and reduce the toxic wastes to non-toxic environment friendly products.

3.1.3 Nano remediation of water pollution

The availability of safe drinking water is one of the major issues with only 8% of the world population has access to pure potable water. People are generally dependent on the ground water for drinking/cooking purposes which are usually having several contaminants like fluoride, nitrates, chloride, toxic heavy metals such as arsenic, lead, and chromium along with radioactive materials which leads to serious health problems. Nanotechnology provides an excellent solution for the purification/ disinfection of ground water using metal- and metal oxide based nano materials such as Ag NPs/Ag ions, TiO_2 NPs, metal doped TiO_2 iron based NPs etc. due to their antibacterial, antifungal, and antiviral properties[27]. Magnetic metallic nano absorbents utilized for the removal of metallic ions like nickel, cadmium, cobalt, and copper are associated with several challenges namely, aggregation, toxicity of the materials involved along with the cost involved. These challenges have been overcome by using zerovalent iron (ZVI) having a core-shell structure. The heavy metals and chlorinated compounds can be reduced via electron donation for ZVI core. Parthna *et al.*[28] have reviewed the application of nanoparticles in water treatment at household level using teabag model developed by Gilman[29] for the removal of arsenic using hydrotalcite. They proposed that same technology can also be further explored using nano adsorbents for the removal of other heavy metals/contaminants. However, in implementing the technology retention of the nanoparticles inside the tea bag should be ensured. This may be done by immobilizing nanoparticles onto a suitable substrate before packing into tea bags. Silver nanoparticles having anti-bacterial properties are used as disinfect in water purification. Besides this, they have also been used to remove the halogenated pesticides and organic pollutants from water. The technology was patented by researchers of the Indian Institute of Technology, Madras and has been commercially applied in India by Aqua guard using silver nanoparticles embedded on activated alumina[30]. Recently, carbon nanotubes (CNTs) have gained attention for their application in water purification especially in desalination devices due to their large surface area, ease of functionalization, high aspect ratio and fast water transport. CNTs also exhibit antimicrobial properties by causing oxidative stress in bacteria and destroying the cell membranes. It has an additional advantage over other disinfection processes like chlorination and ozonation that no toxic byproducts are produced. They can be regenerated by appropriately adjusting the operating conditions, like pH shift[31]. However, the applications of CNTs on commercial scale is facing major challenge of their synthesis with suitable pore size. For example, nano-sized bimetallic mixtures (Pd/Fe, Cu/Fe and Pd/Cu) enhanced the reduction of Cr(VI) compared to using ZVI alone. The improvement was attributed to the reasoning that cementation of a noble metal acts as a reaction catalyst and also protects the metallic surface from inactivation. Nitrate pollution has attracted increasing attention due to the worsening of water pollution. This study focuses on the synergistic effects of zero-valent iron and bimetallic composite carrier catalyst for maximizing the catalytic reduction of nitrate in water to nitrogen gas.

3.1.4 Nano remediation of soil pollution

Soil is a complex tri-phase (solid, liquid, gas) environment with biotic interaction (by microorganisms) and abiotic interaction (by metallic elements) which are affected by pollutants in the soil. Soil micro-organisms are essential for maintaining healthy soil and sustainable agriculture. The advancement in the field of nanotechnology has opened up enormous possibility in remediation of contaminant soil. The effects of metal and metal oxide nano particles on soil microbial activity have been examined by a number of researchers and have found quite contrary responses with different nanoparticles (NPs). The Ag NPs are found to decrease the soil microbial metabolic activity whereas FeO NPs increase it[32]. Cu NPs are toxic for aquatic life but is used as fungicide. Shi et al[33] have studied the effect of application of nano scale zero valent iron (nZVI) and nZVI on a bentonite matrix (B-nZVI) for the removal of Cr(VI) in water and soil contaminated by Cr(VI) and found that B-nZVI was more effective due to its induced aggregation and increased specific surface area. B-nZVI, nanoalginite, and nano carbon are used to immobilize Cd and Pb in polluted soils[34] and their immobilizing efficiencies are compared. Their adsoption capacity for Cd are expressed in descending order as Nzvi>bent-nZVI>nanoalginite>nano carbon whereas for the adsorption capacity for Pb the order is nZVI>nanoalginite> bent-nZVI>nano carbon. Also, the absorption capacities for all these nano-materials for Pb, are lower than those reported for Cd. The best nano-material recommended for remediation of Cd and Pb polluted soils is nZVI as it can be easily prepared, inexpensive and has the highest capacity to adsorb and retain Cd and Pb.

Besides the positive impacts of nano remediation, there are studies that show the possible toxic effects of increasing use of nano particles in environmental remediation on the plant and soil ecosystems[35]. These toxic effects are seen as less germination protein damage, membrane destruction, chlorophyll content, transpiration and photosynthesis etc. and also include plant growth, crop quality, crop yield, nutrient level etc.

3.2 Filtration by nanofilters

Nanofiltration is found to be better in rejection of multivalent ions, pesticides and heavy metals compared with conventional treatment methods. Nano filter is a nanometer sized through-pores membrane with pore sizes from 1-10 nanometers. Nano filtration is generally used for softening water in which it retains calcium and magnesium ions while passing smaller hydrated monovalent ions. Water purification is also done using carbon nanotubes and alumina fibers for nano filtration[36]. It also utilizes the existence of nanoscopic pores in zeolite filtration membranes, as well as nanocatalysts and magnetic nanoparticles. It is done at room temperature so is less costly as compared to distillation which requires heating and then cooling. Extensive research has also been conducted on the potential use of titanium dioxide nanoparticles for membrane fouling reduction. Polyvinyl alcohol (PVA) and polyacrylonitrile (PAN) nanofibres containing silver nanoparticles possess excellent antimicrobial activity thus can be applied to improve the quality of water filtration membranes. Air pollution can also controlled by nanostructured membranes that have pores small enough to separate different pollutants from exhaust. Nanofibre-coated filter media are used for dust removal[37]. Filtration by nano-structured membranes is suitable for several VOCs vapors[38] such as formaldehyde (HCHO) by electrospun polyacrylonitrile (PAN)- based carbon nanofiber (CNF) membrane[39] Further improvement and optimization of nano-structured membranes to capture several gas pollutants is the current area of research in nanotechnology for pollution control. Bioaerosols can rapidly grow in indoor air and cause allergies and infections. Silver and copper nanoparticles filters are used to remove bioaerosols due to their antimicrobial properties. Particulate matter (PM) constitute major air pollutant which causes serious harm to public health. Nanofibrous filters formed by processing four unique metal−organic frameworks (MOFs) having high porosity, tunable pore size, and rich functionalities are reported to be effective in removing $PM_{2.5}$ and PM_{10}[40]. A high-efficiency rotating tribo electric nano generator (R-TENG) -enhanced multilayered antibacterial polyimide (PI) nanofiber air filters is developed for removing ultrafine particulate matter (PM) from ambient atmosphere [41]. That can completely remove all the particles with diameters larger than 0.54 µm with enhanced removal efficiency for smaller particles. Also, the addition of a small amount of silver nanoparticles to the film provides it high antibacterial activity. This technology is suitable for cleaning air, haze management, and bacterial control due to zero ozone release and low pressure drop.

3.3 Detection and sensing

Sensing and timely detection of pollutants is of great importance in environmental protection and pollution control. A comprehensive review on gas sensors has been reported by Kanan et al.[42]. Sensors are also available for detecting marine pollutants[43]. Conventional methods for detection of pollutants include Physical, chemical and biological processes which detect the nature and the concentration of the pollutant. In spite of the fact that these methods are accurate, they need sampling and laboratory analysis which are very time consuming and expensive. The search for naval materials for nano sensors to be used in environmental pollutants detection is more than a decade old now[44]. Nano sensors have following advantages over the conventional sensors-

i. They provide real time data and can detect toxic compounds at ppm & ppb levels e.g. carbon nanotubes modified with semiconducting metal oxide materials like WO_3 composites can detect NO or NO_2 at ppb levels at room temperature.
ii. Coating nano particles with chemical/ biological ligands improves sensor specificity
iii. Size of nano particles can be altered to control the interaction with the pollutant molecule
iv. Conductivity and sensitivity are improved by using nano particles of different metals
v. Process is faster, can detect micro organisms
vi. Use of small multiplex sensors reduce cost and number of devices used
vii. Cost effective due to limited power consumption & effective performance
viii. Are portable analytical tools with features of selectivity and stability,

Applications of nano sensors for the detection of pesticides, metals, and pathogens are critically reviewed[45]. These consist of three components: a nanomaterial (s) namely quantum dots (QDs), metal and metal oxide nanoparticles, and carbon based nanomaterials; a recognition element that provides specificity, and a signal transduction method that provides a means of relaying the presence of the analyte. Nanomaterials have enabled miniaturization, portability, and rapid signal response times. Selectivity is an extremely important facet in the design of a successful biosensor. The recognition elements used in nanosensor include antibodies, aptamers, enzymes and functional proteins microorganisms and other materials that elicit an immune response. For signal transduction, optical, electrochemical, and magnetic methods are employed in nano-enabled sensors. Optical transduction is based on the interaction of a sensing element with electromagnetic radiation whereas electrochemical detection methods are based on the change in current or potential resulting from the interaction between an analyte and an electrode. Magnetic transduction is the use of magnetic nanoparticles to concentrate, separate and purify the analyte in the detection zone. Magnetic transduction method is generally used for detection in biological samples.

Satellite remote sensing is also available for detecting and monitoring marine pollution which covers large and remote areas [46].

3.4 Pollution prevention

Pollution prevention by nanotechnology refers to

i. Reduction in the use of raw materials, water or other resources
ii. Elimination or reduction of waste and
iii. Energy saving, efficient use of energy or involvement in energy production

The implementation of green chemistry principles for the production of nanoparticles and for nanotechnological applications can lead to a great reduction in waste generation, less hazardous chemical syntheses, improved catalysis[47]. The nanocatalysts function at room temperature thus save energy. Another example of reduction in fuel savings of nearly $460 million per year can be attributed to nanomaterial coatings on ships. The ships are damaged due to biofouling - the build-up of damaging biological material costing the shipping industries billions of dollars per year in their maintenance and extra fuel usage due to increased drag. Nano diamonds are expected to increase the life of automotive paints and, thus, can reduce material costs and expenditure Nanoparticulate can be used as catalysts for fossil fuels which will lead to reduced emissions or better energy efficiency, more effective and cheaper solar cells or coatings on windows to reduce heat loss. By introducing new nanostructures and their hybrids with graphene/carbon the storage capacity of Li rechargeable batteries can be increased. The end products CO_2 and H_2O in the Semiconductor photocatalytic remediation process can further lead to fuel production[48].

3.4.1 Molecular nano technology (MNT) in environment protection

MNT refers to building complex structures of atomic/molecular specifications by mechanosynthesis, combining physical principles of chemistry and nanotechnology and molecular technology of life with the principles of engineering[49]. It is advantageous in the sense that it gives definitive results by application of definitive processes whereas conventional processes give inaccurate results. Some of the possible applications of MNT are given below:

3.4.2 Removal of nuclear wastes

Capture, separation, removal and recovery of radioactive uranium from water by using self-propelled microrobots of metal-organic frameworks (MOFs) with added iron atoms and iron oxide nanoparticles to stabilize the structures and make them magnetic, respectively[50]. It can trap radioactive uranium, within their porous structures. Catalytic platinum nanoparticles placed at one end of each rod converted hydrogen peroxide "fuel" in the water into oxygen bubbles, which propelled the microrobots. In simulated radioactive wastewater, the microrobots removed 96% of the uranium in an hour. The team collected the uranium-loaded rods with a magnet and stripped off the uranium, allowing the tiny robots to be recycled.

3.4.3 Reduction in ozone depletion

The chlorine of the ozone depleting substances (e.g. CFCs) in the stratosphere is separated by using sodium containing balloon type nanorobots powered by nano-solar cells. The balloon breaks and the sodium in it combines with the chlorine, forming NaCl that comes to ground[51].

3.4.4 Nanobotics

The graphene-based nanobots can suck pollutants from the oceans in under an hour[52]. These have three components: a graphene oxide exterior to absorb lead or any heavy metal; a nickel core is used to control the nanobots' movement via a magnetic field; and an inner platinum coating functions as an engine and propels the bots forward via a chemical reaction with hydrogen peroxide.

Nano robots are now find applications in environmental protection. Some are given given below

i. Nano sulfurizers eg. Graphene, CNT, CNF etc. can be sent up in the atmosphere to capture SO_2 gas, reduce it to sulphur which is precipitated as dust
ii. Nano sulfur precipitator containing Ca or Mg ion can be sent in the sky to oxidize SO_2 to form $CaSO_4$ or $MgSO_4$
iii. Nano catalytic converter converts NOx into nitrogen & Oxygen
iv. Nano NOx reducer can capture NOx, transforms it to NH_3 and bring it down to ground where fertilizer is needed
v. Nano buffers used to treat acidified water bodies and soil
vi. Nano neutralizer adjusts pH of water or soil either by capturing H^+ from environment or giving of OH- to the environment

4 Conclusions

Nano technology has found applications in every field and can be an effective, efficient and environmental friendly solution of environmental remediation too. The research is going on for search of more and more nano materials and their efficiency/ side effects. But it is also associated with variety of challenges. There are risks of nanoparticles being released during disposal, destruction and recycling into the environment due to ongoing extensive research in the field[53]. So the manufacturers of products have an additional responsibility to develop procedures to minimize possible human and environmental exposure. The health hazards of engineered nanoparticles along with the whole life cycle of these particles should be properly assessed before commercially applying.

References

1 Huang Y, Ho S S , Ho K F, Lee S C, Yu J Z & Louie P K K, *J Hazard Mater.* 186 (2011) 344.

2 *Peden D B, North Carolina Medical Journal* 79 (2018) 309

3 Shahid A & Ismail *S International Journal of Current Advanced Research*, 07 (2018) 10436

4 Mishra R K, Mohammad N & Roychoudhury N, Van Sangyan 3 (2016) 1

5 Holgate, S T, *Clin Med (Lond).* 17 (2017) 8

6 Sweileh, W.M., Al-Jabi, S.W., Zyoud, Sawalha A F *Multidiscip Respir Med* 13 (2018) 15

7 Mohamed, E F (2017) https://doi.org/10.5296/emsd. v6i2.12047

8 URL: https://www.who.int/gho/phe/outdoor_air_pollution/en

9 Junaid,M, Syed,J.H, Abbasi,N.A, Hashmi,M.Z, Malik,R.N & Pei, D.S. *Chemosphere* 191(2018) 651

10 Fullerton,D.G., Bruce,N. and Gordon, S.B., *Trans R Soc Trop Med Hyg*, 102 (2008) 843

11 Chakraborty,D., Mondal,N.K. and Datta,J.KIntern. J. Sustainable Built Environment 3.(2014) 262

12 Radakoviü, S.S., Marjanoviü, M., Šurbatoviü, M., Vukþeviü, G., Jovaševiü-Stojanoviü, M., Ristanoviü, E. Vojnosanit Preg l71.(2014) 1147

13 Tham,K.W., Zuraimi,M.S., Koh,D., Chew,F.T., Ooi,P.L, *Ped Allerg Immunol*;18(2007) 418.

14 Nitasha Khatri & Sanjiv Tyagi *Frontiers in Life Science*, 8(2015)23,

15 URL: http://www.fao.org/3/a-i7754e.pdf

16 http://www.eng.utoledo.edu/aprg/courses/iap/text/part_ctrl1. html

17 Pham T D, Lee B K, Lee C H & Nguyen M V, (2015) https://www.intechopen.com/books/current-air-quality-issues/emission-control-technology

18 URL: https://en.wikipedia.org/wiki/Carbon_sequestration

19 Rashed M N, (2013) http://dx.doi.org/10.5772/54048

20 Montes-Atenas, G.; Valenzuela, F., Physico-chemical wastewater treatment and resource recovery. Intech Open Ltd., Farooq, R.; and Ahmad, Z., (Eds), (2017) https://www.intechopen.com/books/physico-chemical-wastewater-treatment-and-resource-recovery/wastewater-treatment-through-low-cost-adsorption-technologies

21 Ayub S & Changani F, *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development* 4 (2014) 21.

22 Zacchini, M, Pietrini, F, Mugnozza, G S, Iori, V, Pietrosanti, L, and Massacci, A *Water Air Soil Pollut.* 197(2009) 23 doi: 10.1007/s11270-008-9788-7

23 Wuana, R.A. & Okieimen,F.E, *International Scholarly Research Network ISRN Ecology Volume*, (2011) Article ID 402647, doi:10.5402/2011/402647,2

24 Sharma S, Tiwari S, Hasan· A, Saxena V, & Pandey L M, *Biotech* 8 (2018) 216

25 Mohamed, E F, (2017) https://doi.org/10.5296/ emsd.v6i2. 12047

26 Guerra F D, Attia M F, Whitehead D C, Alexis F. *Molecules*. 23 (2018) 1760.

27 Ashraf S, Siddiqa A, Shahida S, Qaisar S. *Heliyon*. 5 (2019)1577

28 Parthna Tc, Sharma S K, Kennedy M D, *Separation & Purification Technology* 199 (2018) 260

29 G.P. Gillman, *Sci. Total Environ*. 366 (2006) 926

30 T. Pradeep, Nair, *Indian Patent No*. 200767, 2 June 2006

31 Gehrke I, Geiser A, Somborn-Schulz A, *Nanotechnol Sci Appl.* 8 (2015) 1

32 He S, Feng Y, Ni J, Sun Y, Xue L, Feng Y, Yu Y, Lin X, Yang L, *Chemosphere.* 147 (2016) 195

33 Shi L N, Zhang X & Chen Z L,Water Res. 45(2011)886. doi: 10.1016/j.watres.2010.09.025

34 Helal I D, Khater H A and Marzoog A, J Arid Land Studies 26 (2016) 129 http://dx.doi.org/10.14976/jals.26.3_129

35 Rastogi A, Zivcak M, Sytar O, Kalaji H M, He X, Mbarki S & M Brestic, *Front Chem*. 5 (2017) 78

36 https://doi.org/10.3389/fchem.2017.00078

37 36_Divya T, Jeevanantham S, Devan P A M and Vishnu S https://www.researchgate.net/publication/331545758

38 Muralikrishnan R, Swarnalakshmi,M & Nakkeeran,E *International Research Journal of Environment Sciences,3* (2014) 82.

39 Scholten E, Bromberg L, Rutledge G C, Hatton T A, ACS Applied Materials Interfaces, 3 (2011) 3902.

40 Lee B U, Yun S H, Jung J H, Gwi-Nam B, *Journal of aerosol science.* 41 (2010) 447

41 Zhang Y, Yuan S, Feng X, Li H, Zhou J, Wang B.*J Am Chem Soc*. 138 (2016) 5785

42 Gu, G Q, Han C B , Lu, C X, He C, Jiang, Gao Z L, Cong Ju Li and Wang Z L, *ACS Nano* 11 (2017) 6211

43 Kanan S M, El-Kadri O M, Abu-Yousef I A & Kanan M C, *Sensors* 9 (2009) 8158

44 Zielinski, O.; Busch, J. A.; Cembella, A. D.; Daly, Kendra L.; Engelbrektsson, J.; Hannides, A. K.; and Schmidt, H., *Ocean Sci*., 5 (2009) 329

45 Riu J, Maroto A, Rius F X, *Talanta* 69 (2006) 288

46 Willner, M R & Vikesland, P J, *J Nanobiotechnol* 16 (2018) 95; doi:10.1186/s12951-018-0419-1

47 Hafeez S, Wong M S, Abbas S, Kwok C Y T, Nichol J, Lee K H, Tang D & Pun L, DOI: 10.5772/intechopen.81657

48 Daun H, Wang D & Li Y, *Chem. Soc. Rev.* (2015), DOI: 10.1039/c4cs00363b

49 Nowack B, DOI: 10.1002/9783527628155.nanotech010, in Nano technology Vol.2: Environmental Aspects

50 URL: https://en.wikipedia.org/wiki/Molecular_nanotechnology

51 Ying Y, Pourrahimi A M, Sofer Z, Matejkova S ́,& Pumera M, *ACS Nano* 13 (2019) 11477

52 URL: https://www.sciencealert.com/graphene-based-nanobots-could-clean-up-the-metal-from-our-oceans

53 URL:https://en.wikipedia.org/wiki/Pollution_from_nanomaterials